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FLIGHT INVESTIGATION OF THE EFFECTS ON AIRPLANE

STATIC LONGITUDINAL STABILITY OF A BUNGEE

AND ENGINE-TILT MODIFICATIONS

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SUMMARY

Flight tests have been conducted to evaluate an elevator
stick-force bungee and engine tilt as methods of improving
the longitudinal-control characteristics of an existing air-
plane. Particular emphasis was placed on measuring the effect
on the stick-free stability in the power-approach condition.
The stick-force bungee was the simplest and most effec-
tive modification. It is indicated, however, that when large
changes in elevator trim-tab angle are required objectionable
stick-force changes with speed and power will be induced.

The use of engine tilt reduced the stick-force changes
with power, but the stability characteristics were not
improved sufficiently to justify the modification.

The effects of both the bungee and the engine tilt could
be calculated with sufficient accuracy for a preliminary
evaluation of a proposed installation.

A simple flight-test method of selecting the bungee
installation required to correct given unsatisfactory stick-
free-stability characteristics is presented in an appendix to
the report.

INTRODUCTION

It is frequently necessary to modify the longitudinal-
stability and -control characteristics of an existing air-
plane in order to correct critical deficiencies. These
deficiencies are most commonly induced by changes in the air-
plane configuration to meet increased performance require-
ments, changes in the magnitude and disposition of the useful
load, or lack of sufficient information for the preliminary

design or weight and balance estimates. The modifications to be employed should be simple as well as effective and should not change existing satisfactory characteristics. The most effective modifications that can easily be made are the elevator stick-force bungee, engine tilt, and the springy tab, or spring-loaded elevator trim tab.

This report summarizes the results of flight tests of the bungee and engine-tilt modifications installed on a late model carrier-based fighter aircraft which had proved during the service acceptance trials to be unstable stick free in the power-approach condition (carrier-approach). The springy tab was not installed on the test airplane; however, a detailed discussion of this additional type of modification may be found in reference 1.

DESCRIPTION OF AIRPLANE AND MODIFICATIONS

The Basic Airplane

The test airplane was an experimental model of a low-wing, single-place, carrier-based (VF) type monoplane equipped with a tricycle landing gear. The airplane is powered by both a reciprocating engine driving a three-blade tractor propeller, and a jet-propulsion unit mounted behind the pilot's compartment and exhausting through a tail pipe terminating at the extreme aft end of the fuselage. A three-view drawing and the general specifications of the airplane are presented in figure 1 and tables I and II, respectively.

The activity factor of the propeller (per blade) is 120. The propeller side-force factor (per blade) is 112. The force and motion characteristics of the elevator control system are presented in figures 2 and 3. Figure 2 is a plot of the variation of elevator angle with stick position. Figure 3 shows the amount of force required to move the control stick slowly back and forth over its complete range when there are no air loads acting on the tail surfaces. Although figure 3 indicates an acceptably low friction of ± 2 pounds it should be noted that in a case like the present one, where the stick-free stability was such that very low pull forces were required at speeds below the trim speed, the reduction of friction to the minimum possible value is very desirable.

The Modifications

Figure 4 is a schematic diagram of the elevator stick-force-bungee installation. The force characteristics of the

long coil springs connected to the elevator control quadrants were determined from figure 3 by comparing the data with and without the bungee. The springs supplied a force equivalent to a 9.5-pound push on the stick. In addition to the effect of the bungee, the NACA stick-force recorder acted as a bob-weight, adding two more pounds push force for each unit of normal acceleration. This effect was caused by the configuration of the control stick, which is illustrated in figure 4.

The engine-tilt modification was accomplished by the airplane manufacturer by changing a spare front engine and mount so that the thrust axis was tilted 4° nose down with respect to the fuselage reference line. The geometry of this change is given in figure 5. The 4° tilt increased the moment arm of the thrust forces about the center of gravity from 3.6 percent M.A.C. to 9.9 percent M.A.C. in the flap and gear-down configuration.

INSTRUMENTATION

The elevator angle and stick force were recorded photographically by standard NACA instruments synchronized by an electric chronometer. In the range of stick-force data presented the error in elevator angle due to stretch in the control cables between the elevator and the recorder did not exceed ±0.5°.

The elevator trim-tab data were obtained by applying a calibration made with no load acting on the surface to the values noted by the pilot from the standard cockpit position indicator. The accuracy of the tab-angle data presented is ±0.5°.

The values of indicated airspeed were determined from a standard NACA recording system connected to a swivelling airspeed head boom. This system was considered to be accurate within ±2 miles per hour, and no correction for position error was applied.

The normal acceleration factor A_z and engine operating conditions were noted by the pilot from calibrated standard indicating instruments.

TESTS AND RESULTS

The static longitudinal-stability characteristics were measured in each of the four flight conditions specified in

the following table:

Condition	Weight (lb)	Manifold pressure (in. Hg)	Engine speed setting (rpm)	Brake-horse-power	Flap and gear position	Trim speed (mph)
Power-on clean	9300	38	2600	1030	Up	170
Glide	9200	Throttled	Idle	-----	Up	Same tab setting as power-on clean
Power-approach	9300	28	2500	730	Down	[a]103
Landing	9200	Throttled	Idle	-----	Down	Same tab setting as power-approach

[a]$1.15V_{S_L}$

   The static longitudinal-stability characteristics of the airplane for each modification configuration are presented in figures 6 through 10 and summarized in table III. The evaluations of table III were made by comparing the characteristics of the modified airplane to the characteristics of the original airplane at two center-of-gravity positions; the normal (27 percent M.A.C.), figure 6, and the forward (22 percent M.A.C.) figure 7.

   In each airplane configuration the data for the power-approach and landing conditions were taken at the same elevator trim-tab setting so that the data would show directly the stick-force changes with power as well as those with speed. The same is true of the power-on clean and glide conditions. These stick-force changes have been summarized in table IV.

   Tests were also conducted to determine the effect of the modifications on the elevator stick-force gradients in maneuvering flight. These data have been grouped directly into a summary plot in figure 11. The flight conditions are specified on the figure.

DISCUSSION

Bungee

The bungee modification is used to obtain stick-free
static longitudinal stability without affecting the stick-
fixed characteristics or the elevator stick-force gradients
in maneuvering flight. Although it is usually defined and
referred to by the characteristics of the spring alone the
complete modification actually consists of two related changes
in the control system: an increment in nose-up elevator trim
tab (down-tab deflection), and a constant tension spring.
Since most of the difficulty encountered in the selection of
a satisfactory bungee installation is due to the magnitude of
the tab deflections required, it is useful to regard this
quantity rather than the force of the spring as the primary
variable. A more complete discussion of the use of spring
moments, from a different point of view, is presented in
reference 2. In actual practice, of course, once the size of
the spring has been determined the trim tab is used in the
normal manner with no definite increment being set by the
pilot.

The effect of these two changes is best illustrated by
considering the variation of elevator stick force required
for level flight with the dynamic pressure q. The increment
in tab deflection changes the slope dF_e/dq by rotating the
curve about the intercept on the zero q axis. The force of
the bungee spring does not affect the slope but shifts the
curve parallel to the force axis a constant amount equal to
the force required to hold the stick in neutral with no load
acting on the control surfaces. In terms of the flight-test
data used to demonstrate stick-free stability, the increment
in trim-tab angle changes the stick-force gradient dF_e/dV_1
to the desired value and the bungee spring displaces the curve
sufficiently to restore trim $(F_e = 0)$ at the desired speed.
A flight-test method of selecting the bungee installation
required to correct given unsatisfactory stick-free-stability
characteristics is presented in appendix B.

A summary is presented in figure 12 of the effect of 14°
more nose-up tab and bungee spring of 9.5 pounds on the stick-
free characteristics of the airplane in the power-approach
condition. The characteristics calculated from the tab-
effectiveness data of figure 13 and the equations used in
appendix B agree quite well with the flight-test data.

Although the desired degree of stick-free stability was
readily obtained by use of the bungee modification, the large
increment in trim tab necessary induced objectionable

stick-force changes with speed in the high-speed range and
with power. As noted in table IV, the additional pull force
required when the power is reduced from the power-approach
condition to the landing condition was increased from 4 to 11
pounds. Increasing the speed from 170 to 350 miles per hour
without retrimming resulted in a push force of 20 pounds when
the bungee was installed as compared to 11 pounds without the
bungee. Although these stick-force changes are not excessive
they were regarded as objectionable and might become excessive
on some designs. The stick-force changes with speed inherent
in the bungee design might be eliminated by changing to the
springy tab modification discussed in reference 1.

The magnitude of the stick-force changes with power in-
duced by the bungee installation depends on the amount of
additional tab deflection used and the effect of the slip-
stream on the trim-tab effectiveness $dF_e/d\delta_t$. If the trim-
tab deflection which requires the entire bungee force for trim
in the power-approach condition is much less effective when
the power is cut, the major portion of the constant bungee
spring force remains as an increment to the stick-force
changes. For this change of power in the test installation
the tab effectiveness was reduced 50 percent as the data in
figure 13 indicate.

These stick-force changes can be lowered by reducing the
effect of the slipstream on the tab. A set of elevators
having trim tabs located approximately 30 inches outboard of
the position indicated in figure 1 were proposed and tested
by the staff of the Ames 40- by 80-foot wind tunnel. The test
data, showing the variation in $dC_{he}/d\delta_t$ (which results from
the variation in q_{tab}/q_o), are reproduced in figure 14.
The effect of slipstream, although still large, is definitely
reduced on the outboard tabs. The effect of change of power
on the stick forces required for trim would be proportionally
reduced.[1]

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[1] Similar considerations apply to the use of a springy tab,
since its effectiveness depends primarily upon the variation
of q_{tab} with flight speed. Tests in the Ames 40- by 80-foot
wind tunnel indicated that for the test airplane in the power-
approach configuration the action of the slipstream was such
that, with decreasing speed, q_{tab}/q_o increased as q_o de-
creased, thereby reducing the variation of q_{tab} with flight
speed and the potential effectiveness of a springy tab in-
stallation.

Although the tab effectiveness in the power-on clean condition was not measured in flight it should be noted that large trim-tab deflections used to obtain stability at low speeds will be much more effective at high speeds and induce large stick-force changes with speed.

The data of figure 11 show that, as expected, the bungee modification did not affect the stick-force gradients in maneuvering flight.

Engine Tilt

The use of an inclined thrust axis to reduce the destabilizing effects of power results in greater negative pitching-moment slopes, $\partial C_m/\partial C_L$ at T_c for constant power, in effect moving both the stick-fixed and stick-free neutral points aft. The method of reference 3 has been used to compute the effect of $4°$ tilt on the pitching moment of the test airplane equipped with double-slotted flaps in the power-approach condition. The increments of pitching moment are presented in figure 15 as a function of airplane lift coefficient. At a lift coefficient of 1.24 corresponding to the trim speed of 1.15 V_{S_L} or 103 miles per hour, the total change in $\partial C_m/\partial C_L$ is -0.012, corresponding to an approximate rearward movement of the stick-fixed neutral point of only 1.2 percent M.A.C.

The effects of tilt as measured in flight in the power-approach condition are summarized in figure 16. The data of figure 15 and unpublished elevator-effectiveness data were used to compute the stick-fixed characteristics of the airplane with tilt. The calculated effect agrees very well with that measured, indicating that the method of reference 3 is satisfactory for use in the preliminary evaluation of a proposed modification.

No unsatisfactory effects induced by tilt were noted during the flight tests. The stick-force changes with power were generally reduced as indicated by the data in table IV. This effect is explained by the fact that the tilt reduces the normal nose-up pitching moment due to power, consequently reducing the δ_c change, and therefore the force change, required. The trim-tab effectiveness in the power-approach condition was not changed.

The stick-force gradients in maneuvering flight were also unaffected, as shown in figure 11. This would be expected, since the tilt affects only the $\partial C_m/\partial C_L$ at T_c for constant power and not $\partial C_m/\partial C_L$ at constant T_c.

The data of figure 15 indicate that most of the effect
of tilt on the pitching-moment slope is due to the direct
propeller-thrust forces. The effectiveness of any proposed
tilt installation therefore depends mainly on the amount of
increase of the moment arm of the thrust forces about the air-
plane center of gravity. In order to obtain the maximum
benefit from a given degree of tilt, the point of rotation of
the engine installation obviously should be as far forward as
possible. As shown in figure 5 in the present test instal-
lation the thrust moment arm would have been 43 percent larger
if the engine could have been rotated about the propeller hub
rather than the firewall. The movement of the stick-fixed
neutral point would have been increased roughly from 1.2 to
2.5 percent M.A.C. Unfortunately the position of the point
of rotation is usually fixed fairly well aft because of the
necessity of avoiding complicated cowling and fuselage nose
structure changes. -

It should be emphasized that it is necessary to simulate
the full-scale airplane installation very carefully when
powered wind-tunnel models are used to evaluate a proposed
application of tilt. It is very important to insure that the
thrust moment arm is constant, that is, that the particular
position of the center of gravity with respect to the thrust
line is held constant.

The tilt modification is obviously less effective and
flexible than the bungee, particularly when applied to an
existing airplane.

CONCLUSIONS

The following conclusions have been drawn from consider-
ation of the modifications as methods of improving the static
longitudinal-stability characteristics of an existing airplane:

1. The elevator stick-force bungee was the simpler and
more effective modification, although objectionable stick-
force changes with speed in the high-speed range and with
power were induced by the large increments in elevator trim-
tab angle required. The stick-force changes with power could
have been reduced by moving the elevator trim tabs outboard
to reduce the effect of the slipstream.

2. Even though desirable reductions in the stick-force
changes with power were obtained, the engine-tilt modifi-
cation was not effective enough in this application to warrant
using it solely to increase static stability. The effective-
ness would have been increased if the engine installation could

have been rotated about the propeller hub rather than a point farther aft on the firewall.

3. The effects of both the bungee and tilt modifications could be computed with satisfactory accuracy for a preliminary evaluation of a proposed modification.

Ames Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Moffett Field, Calif., December 2, 1946.

APPENDIX

SYMBOLS

Standard NACA symbols used throughout this report are as follows:

A_Z the ratio of the net aerodynamic force along the airplane Z-axis (positive when directed upward) to the weight of the airplane

C_{h_e} elevator hinge-moment coefficient

C_{h_δ} rate of change of elevator hinge moment with elevator angle at constant airplane lift coefficient

$\partial C_m / \partial C_L$ rate of change of airplane pitching moment with airplane lift coefficient at T_c for constant power

C_L airplane lift coefficient

C_m airplane pitching-moment coefficient

D propeller diameter, feet

F_e elevator stick force (pull force positive), pounds

$M.A.C.$ mean aerodynamic chord, feet

q dynamic pressure $(\frac{1}{2}\rho V^2)$, pounds per square foot

T axial propeller thrust, pounds

T_c thrust coefficient $(T/\rho V^2 D^2)$

V true airspeed, feet per second

V_i indicated airspeed, miles per hour, defined by the usual formula by which standard airspeed meters are calibrated

V_{S_L} airplane stalling speed in the landing configuration (flaps and gear down)

δ_e elevator angle measured with respect to the horizontal stabilizer (down-elevator positive), degrees

δ_t elevator trim-tab angle measured with respect to the elevator (down-tab positive), degrees

$\dfrac{\text{stick force per g}}{} \quad \dfrac{\text{change in elevator stick force from trim}}{\text{change in } A_Z \text{ from trim}}$

Special subscripted symbols used in appendix B are as follows:

F_e elevator stick force at any speed with the bungee installed

F_{e_0} elevator stick force at any speed without the bungee installed

$dF_e/d\delta_t$ rate of change of elevator stick force with trim-tab angle at constant airspeed

The value of the above quantities at a given airspeed is specified by placing the quantity in brackets and appending one of the following subscripts:

$V_{i_{trim}}$ trim airspeed (F_e and $F_{e_0} = 0$)

V_{i_1} some arbitrary airspeed $V_{S_L} < V_{i_1} < V_{i_{trim}}$

$V_{i_{max}}$ maximum level-flight airspeed

Thus

$(F_e)_{V_{i_1}}$ elevator stick force with bungee installed at an arbitrary airspeed $V_{S_L} < V_{i_1} < V_{i_{trim}}$

F_{e_B} increment of elevator stick force due to addition of
             bungee spring identified as the force required to
             hold the stick in neutral with no load on the con-
             trol surfaces

$\Delta\delta_t$ change in elevator trim-tab angle required to restore
             trim ($F_e=0$) with the bungee installed at a given
             trim speed and in a condition specified by the
             subscripts

Subscripts

PA   power-approach condition

P   power-on clean condition

L   landing condition

APPENDIX B

FLIGHT-TEST METHOD OF SELECTING A SATISFACTORY

BUNGEE INSTALLATION

Given an airplane with unsatisfactory stick-free stability
characteristics, a flight-test method of selecting a satis-
factory corrective bungee installation is presented in the
following outline:

I. Selection of bungee installation.

    A. Flight-test data required (measured at normal center-
        of-gravity position in critical condition, in this
        case power-approach).

1. Variation of F_{e_0} with V_i

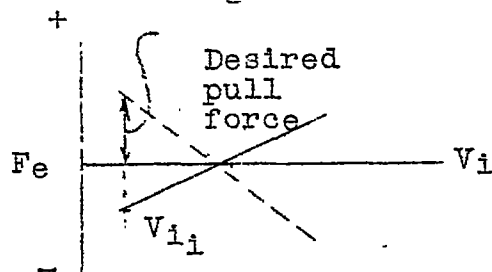F_e ... V_i
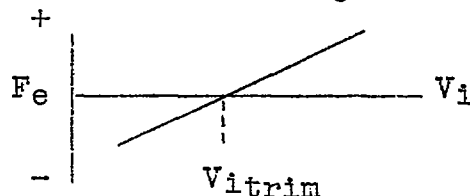
$V_{i_{trim}}$

2. $dF_e/d\delta_t$ at $V_{i_{trim}}$ and V_{i_1}

3. Stick-force friction (should be < 2 pounds)

B. Determine desirable pull force at V_{i_1} from pilot's comment or criteria such as presented in reference 4 where stick-force equals $-0.05 \left(V_{i_1} - V_{i_{trim}}\right)$ provided that the friction is less than 2 pounds.

C. The desired change is

Desired pull force

F_e ... V_i

V_{i_1}

Note that the desired stick-free characteristics are approximated by specifying the force at only two speeds, V_{i_1} and $V_{i_{trim}}$; the exact stick-force gradient is not determined. The change is produced by changing the trim-tab angle an amount $\Delta\delta_t$ and adding a constant bungee spring force F_{e_B} identified as the elevator stick-force required to hold the control stick in neutral with

no load acting on the surface. The effect of
these two changes on the stick force at a given
airspeed is

$$F_e = F_{e_0} + F_{e_B} + (dF_e/d\delta_t)\Delta\delta_t$$

D. The equations for the two specified points on the
desired stick-force variation with indicated
airspeed are

at V_{i_1}, $(F_e)_{V_{i_1}} = (F_{e_0})_{V_{i_1}} + F_{e_B} + (dF_e/d\delta_t)_{V_{i_1}} \Delta\delta_{t_{PA}}$ (1)

at $V_{i_{trim}}$, $(F_e)_{V_{i_{trim}}} = (F_{e_0})_{V_{i_{trim}}} + F_{e_B}$

$$+ (dF_e/d\delta_t)_{V_{i_{trim}}} \Delta\delta_{t_{PA}} \qquad (2)$$

Noting that both $(F_e)_{V_{i_{trim}}}$ and $(F_{e_0})_{V_{i_{trim}}}$ are

zero by definition, solving equation (2) for
F_{e_B} and substituting in equation (1)

$$F_{e_B} = -\left(\frac{dF_e}{d\delta_t}\right)_{V_{i_{trim}}} \Delta\delta_{t_{PA}}$$

$$\Delta\delta_{t_{PA}} = \frac{(F_e)_{V_{i_1}} - (F_{e_0})_{V_{i_1}}}{\left(\frac{dF_e}{d\delta_t}\right)_{V_{i_1}} - \left(\frac{dF_e}{d\delta_t}\right)_{V_{i_{trim}}}}$$

II. Consideration of possible unsatisfactory induced effects.

A. Flight-test data required.

1. Stick-force change at $V_{i_{trim}}$ due to cutting power from the power-approach condition to the landing condition without retrimming, $\Delta Fe_{0_{power}}$.

2. Stick-force change encountered in increasing speed from $V_{i_{trim}}$ to $V_{i_{max}}$ in power-on clean condition, $\Delta Fe_{0_{speed}}$.

3. $dFe/d\delta t$ at $V_{i_{trim}}$ in the landing condition and at $V_{i_{max}}$ and $V_{i_{trim}}$ in the power-on clean condition.

B. Stick-force change with power with bungee installed will be

$$\Delta F_{e_{power}} = \Delta F_{e_{0_{power}}}$$
$$+ \Delta \delta t_{PA} \left[\left(\frac{dF_e}{d\delta t}\right)_{LV_{i_{trim}}} - \left(\frac{dF_e}{d\delta t}\right)_{PA V_{i_{trim}}} \right]$$

$\Delta F_{e_{power}}$ should be < 35 pounds.

C. Ability to trim in landing condition with bungee installed. Tab angle required for trim in landing condition with bungee installed will be

$$\delta t_L = \delta t_{L_0} + \Delta \delta t_{PA} + \Delta F_e \times \frac{1}{(dF_e/d\delta t)_{LV_{i_{trim}}}}$$

δt_L must be within tab-angle range.

D. Stick-force changes with speed. Stick-force change due
to increasing speed from $V_{i_{trim}}$ to $V_{i_{max}}$ in the
power-on clean condition with the bungee installed
will be

$$\Delta F_{e_{speed}} = \Delta F_{e_{0_{speed}}}$$

$$+ \Delta \delta t_p \left[\left(\frac{dF_e}{d\delta t} \right)_{P V_{i_{max}}} - \left(\frac{dF_e}{d\delta t} \right)_{P V_{i_{trim}}} \right]$$

$\Delta F_{e_{speed}}$ should be < 35 pounds.

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TABLE I.- BASIC DIMENSIONAL DATA OF THE TEST AIRPLANE.

Item	Wing	Horizontal tail	Vertical tail
Area, sq ft......	275	63.86	31.35
Span, ft.........	40	17.5	6.79
Aspect ratio.....	5.82	4.45	1.45
Taper ratio......	0.5	0.667	0.353
M.A.C., in.......	87.55	49.3	61.95
Dihedral of chord plane, deg.............	7.5	0	----
Incidence of root chord to thrust line, deg............	1	1.5	---
Geometric twist, deg......	0	0	0
Root section....	65,2-117(a=1.0)	65,2-015 modified	63,2-012 modified
Tip section.....	65,2-115(a=0.5)	65,2-015 modified	63,2-012 modified
Percent straight line..	0	65	84.55
Tail length, ft (from 0.25 M.A.C. of wing to 0.25 M.A.C. of tail).......	------------	17.46	18.69
Tail volume, $\frac{l_H S_H}{S_w t_w}$, $\frac{l_v S_v}{S_w b_w}$......	------------	0.600	0.054

TABLE II.- DIMENSIONAL CHARACTERISTICS OF THE MOVABLE SURFACES OF THE TEST AIRPLANE.

Item	Elevators	Rudder	Flaps	Ailerons
Area aft of hinge line (sq ft, both sides)	20.84	8.92	39.6	12.8
Area affected by movable surface (sq ft)	58.83	26.44	165.4	72.0 (approx.)
Span (ft, one side)	7.85	5.98	10.03	7.54
M.A.C. (ft)	1.365	1.532	----	0.958
Hinge-line location (percent chord)	65.0	----	----	11.5 in. from trailing edge
Aerodynamic balance and type of flap	Internally sealed between hinges (fig. 1)	Overhanging sealed	Double slotted	Sealed internal
Travel (deg)	12.5 down 27.5 up	29.6 right and left	35 down	22 up, 13 down
Tabs	Trim (area 1.27 sq ft, each; span 1.812 ft) 25° travel up and down	Trim (area 0.506 sq ft span 1.5 ft) 25° travel right and left	----	Trim on left aileron only (area 0.89 sq ft, span 2.81 ft) 15° travel up and down

TABLE III.— MODIFICATION CONFIGURATIONS AND EVALUATIONS.

Approximate center of gravity location (percent M.A.C.)	Bungee force (lb)	Engine tilt (deg)	Figure number	Evaluation	Remarks
27	----	----	8	Unsatisfactory	Unstable in power-approach condition, unfavorable stick-force gradient at low speeds in power-on clean condition.
21.5	----	----	9	Marginally satisfactory	Neutral stability in power-approach condition, stick-force changes with power larger than desirable
27	9.5	----	10	Satisfactory	Stick-force changes with power and with speed in the high-speed range larger than desirable.
27	----	4	11	Marginally satisfactory	Neutral stability in power-approach condition, unfavorable stick-force gradient at low speeds in the power-on clean condition.
27	9.5	4	12	Marginally satisfactory	Airplane cannot be trimmed in power approach condition, stick-force changes with power and speed in the high-speed range larger than desirable, excessive stick force required to land.

TABLE IV.- STICK-FORCE CHANGES DUE TO POWER AND TO SPEED IN THE HIGH-SPEED RANGE.

Center of gravity (percent M.A.C.)	Bungee force (lb)	Tilt	Flaps	δt (deg)	Stick force changes		
					[a]Power in power-approach condition (lb)	[b]Power in power-on clean condition (lb)	[c]Speed in power-on clean condition (lb)
27	None	None	Double-slotted	4 Nose up	4.0	3.5	-11.0
21.5	None	None	Double-slotted	16 Nose up	11.5	5.0	-16.5
27	9.5	None	Double-slotted	18 Nose up	11.0	8.0	-20.0
27	None	4°	Double-slotted	8 Nose up	3.5	1.5	-10.0
27	9.5	4°	Double-slotted	Full nose up	[d]10.0	4.0	-26.0
27	None	None	Single-slotted	3.5 Nose down	1.5	----	----
27	7.5	None	Single-slotted	6 Nose up	6.5	----	----

[a]Measured at trim speed (1.15 V_{S_L}) while reducing brake horsepower from 730 to 0.
[b]Measured at trim speed while reducing brake horsepower from 1030 to 0.
[c]Measured from trim speed, 170, to 350 miles per hour.
[d]Could not be trimmed at 1.15 V_{S_L} in power-approach condition.
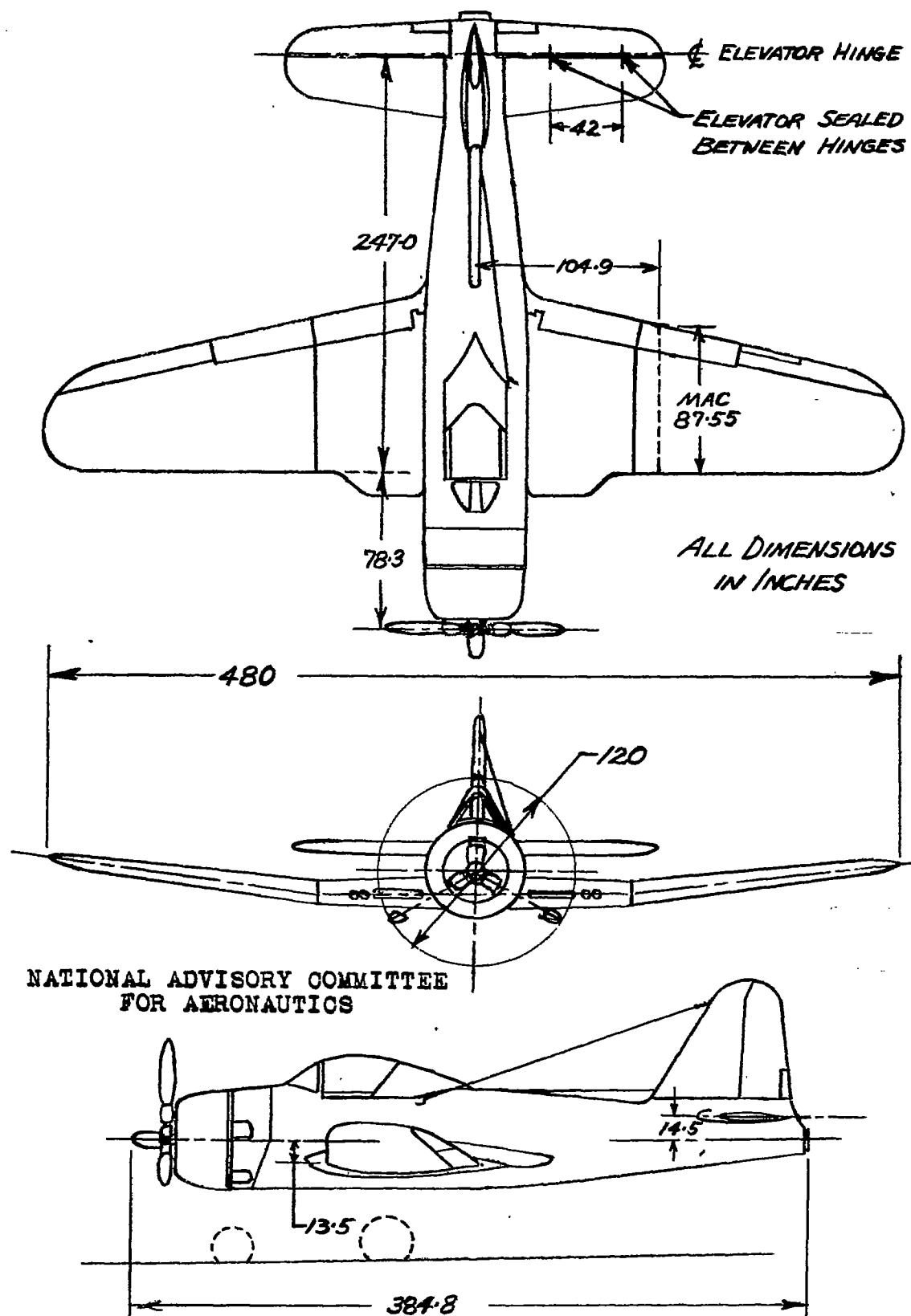
FIGURE 1. — GENERAL ARRANGEMENT OF THE TEST AIRPLANE.

FULL UP
24·8°

FULL DOWN
10·5°

ELEVATOR ANGLE, DEG   DOWN   UP

POSITION OF TOP OF STICK, INCHES

8   4 FORWARD 0 AFT 4   8

±2 LB FRICTION

9·5 LB SPRING

WITH
BUNGEE

WITHOUT
BUNGEE

2 LB UNBALANCE DUE TO STICK FORCE RECORDER

STICK FORCE, LB   PUSH 0 PULL

ELEVATOR ANGLE, DEG

20   10 DOWN 0 UP 10   20   30
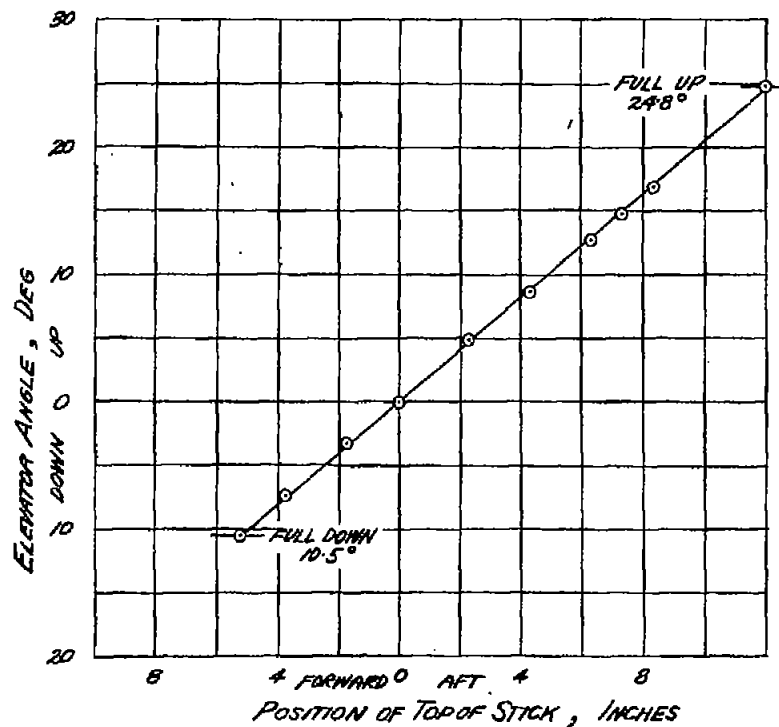
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FIGURE 2. ——— ELEVATOR CONTROL GEARING.
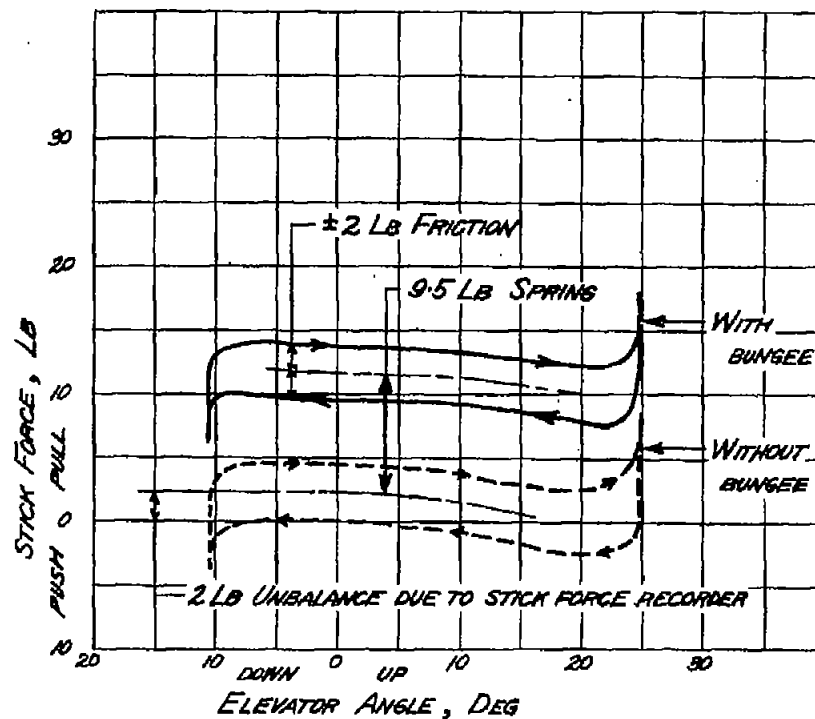
FIGURE 3. ——— STICK-FORCE VARIATION WITH STICK
MOVEMENT AT NO-LOAD CONDITION FOR
ELEVATOR CONTROL SYSTEM WITH AND
WITHOUT BUNGEE.

NACA STICK FORCE
RECORDER

ELEVATOR CONTROL
CABLES
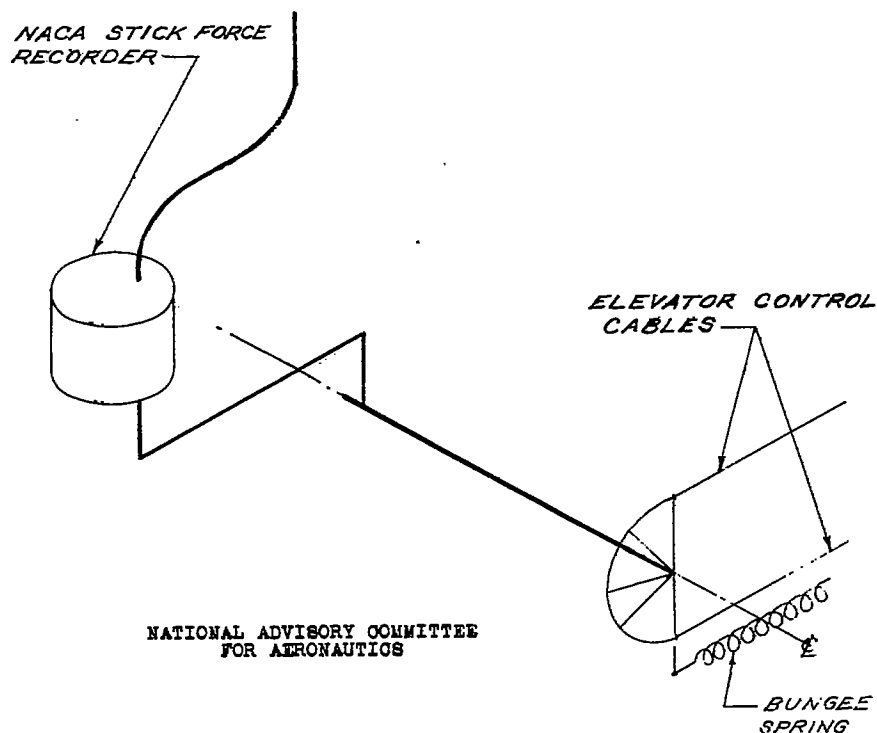
BUNGEE
SPRING

FIGURE 4. — SCHEMATIC DIAGRAM OF ELEVATOR
STICK FORCE BUNGEE AND NACA
STICK FORCE RECORDER INSTALLATION.

LE OF MAC

54.6

8.67 = 9.9% MAC

3.15 = 3.6% MAC

4°

TILT ABOUT PROPELLER HUB

ACTUAL TILTED THRUST LINE

NORMAL THRUST LINE

CG

FLAPS AND GEAR
DOWN

12.42 = 14.2% MAC
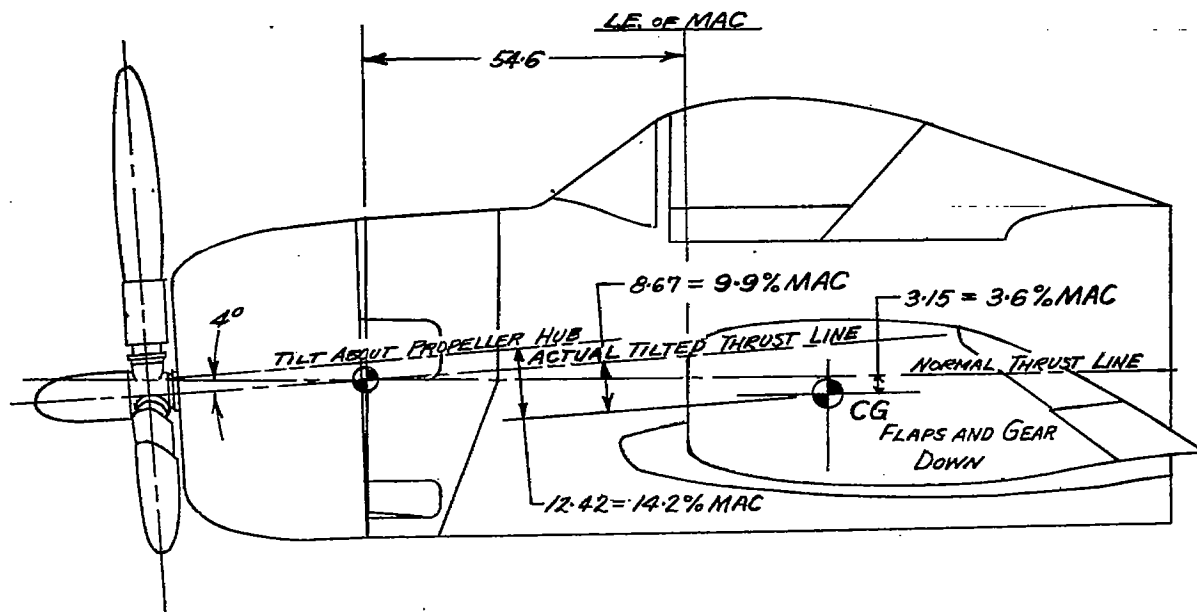
FIGURE 5. —— THE GEOMETRY OF THE ENGINE-TILT
MODIFICATION.

Fig. 6
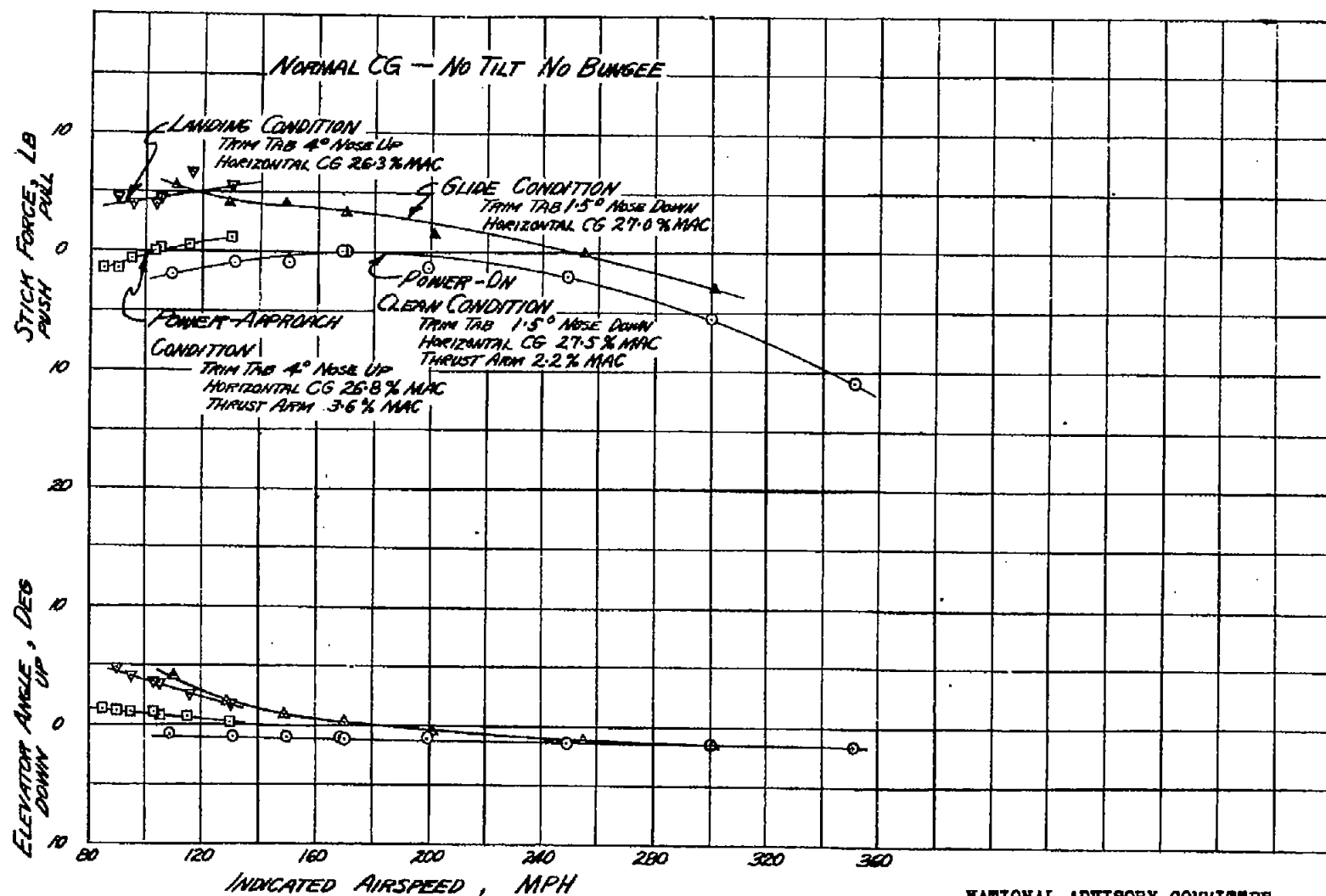
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FIGURE 6. —STATIC LONGITUDINAL STABILITY AT NORMAL CG (27% MAC) WITHOUT
ENGINE TILT OR STICK FORCE BUNGEE.
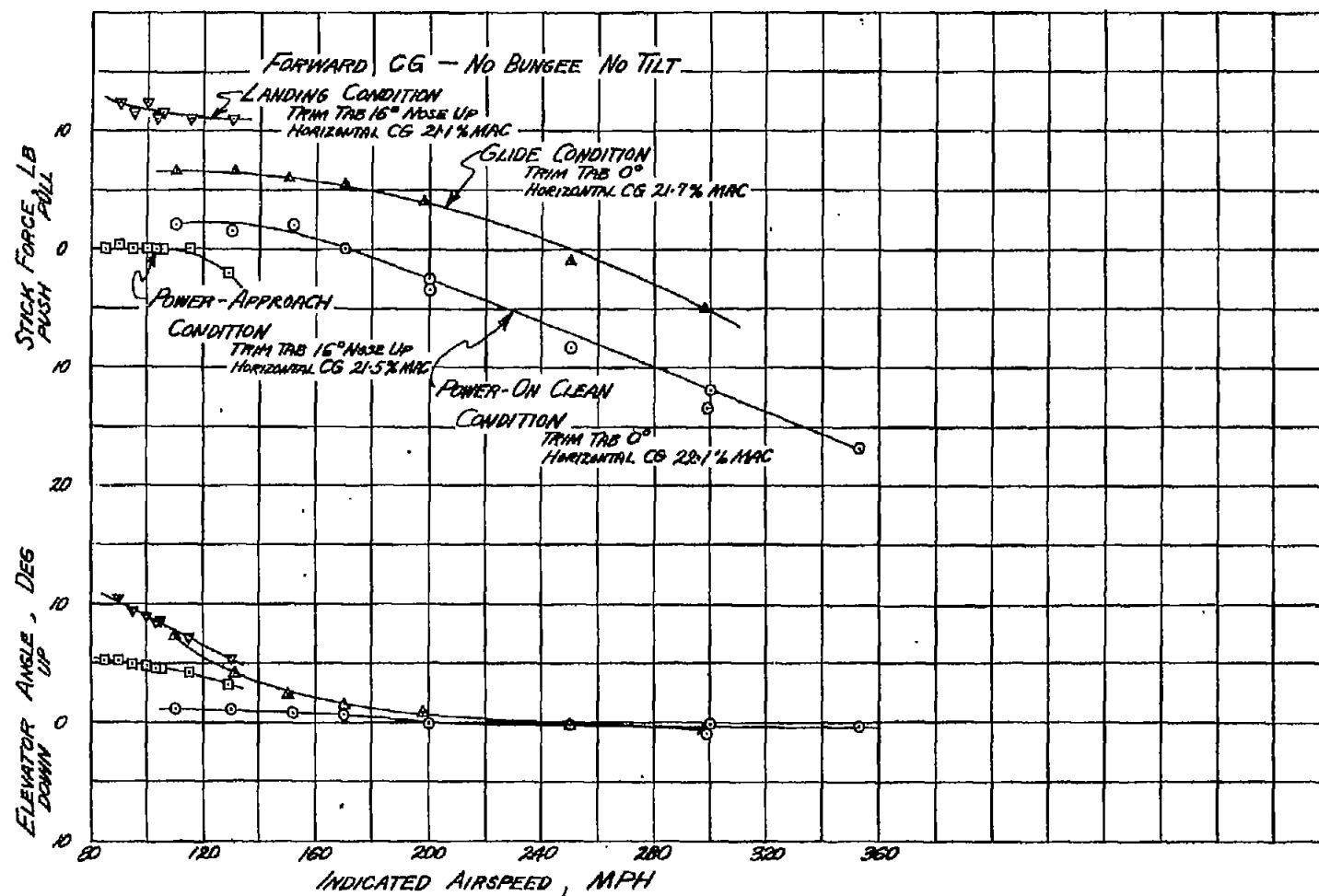
FIGURE 7. — STATIC LONGITUDINAL-STABILITY CHARACTERISTICS AT CG = 22% MAC, NO ENGINE TILT OR STICK FORCE BUNGEE.

Fig. 7
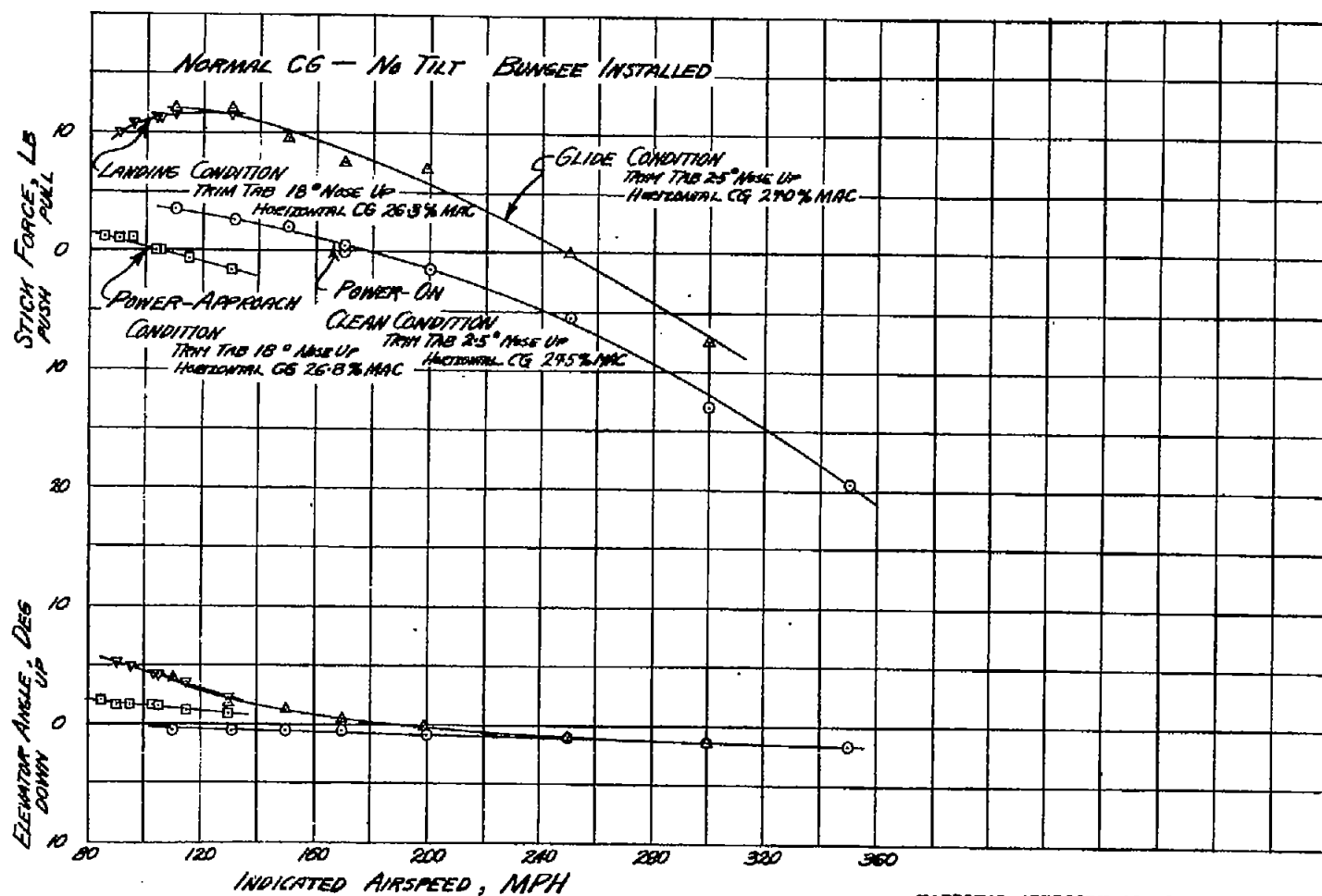
FIGURE 8. — STATIC LONGITUDINAL STABILITY AT NORMAL C.G. WITH ELEVATOR STICK FORCE BUNGEE INSTALLED AND NO ENGINE TILT.
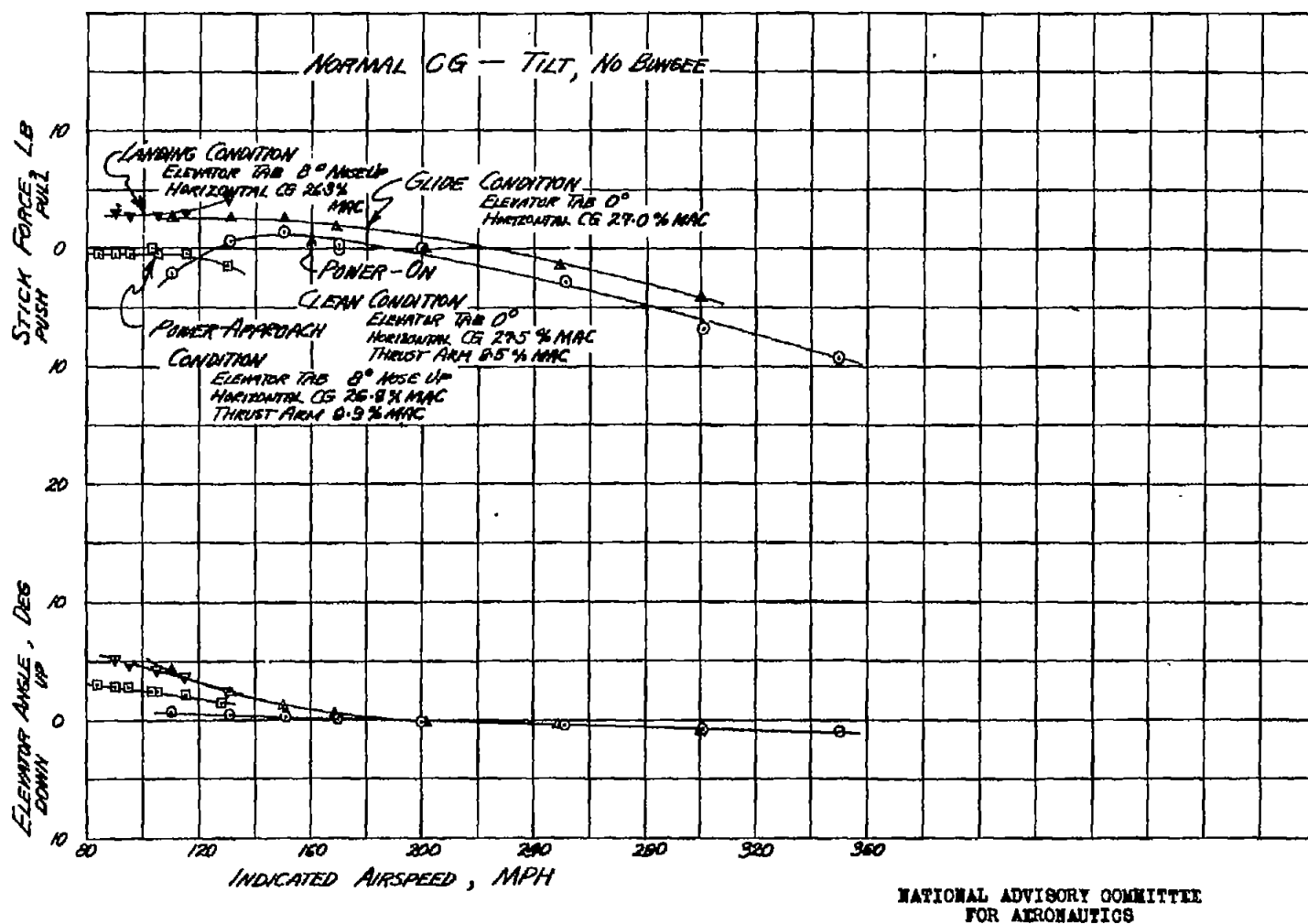
Fig. 8

FIGURE 9. — STATIC LONGITUDINAL STABILITY AT NORMAL CG WITH TILTED ENGINE, WITHOUT STICK FORCE BUNGEE.
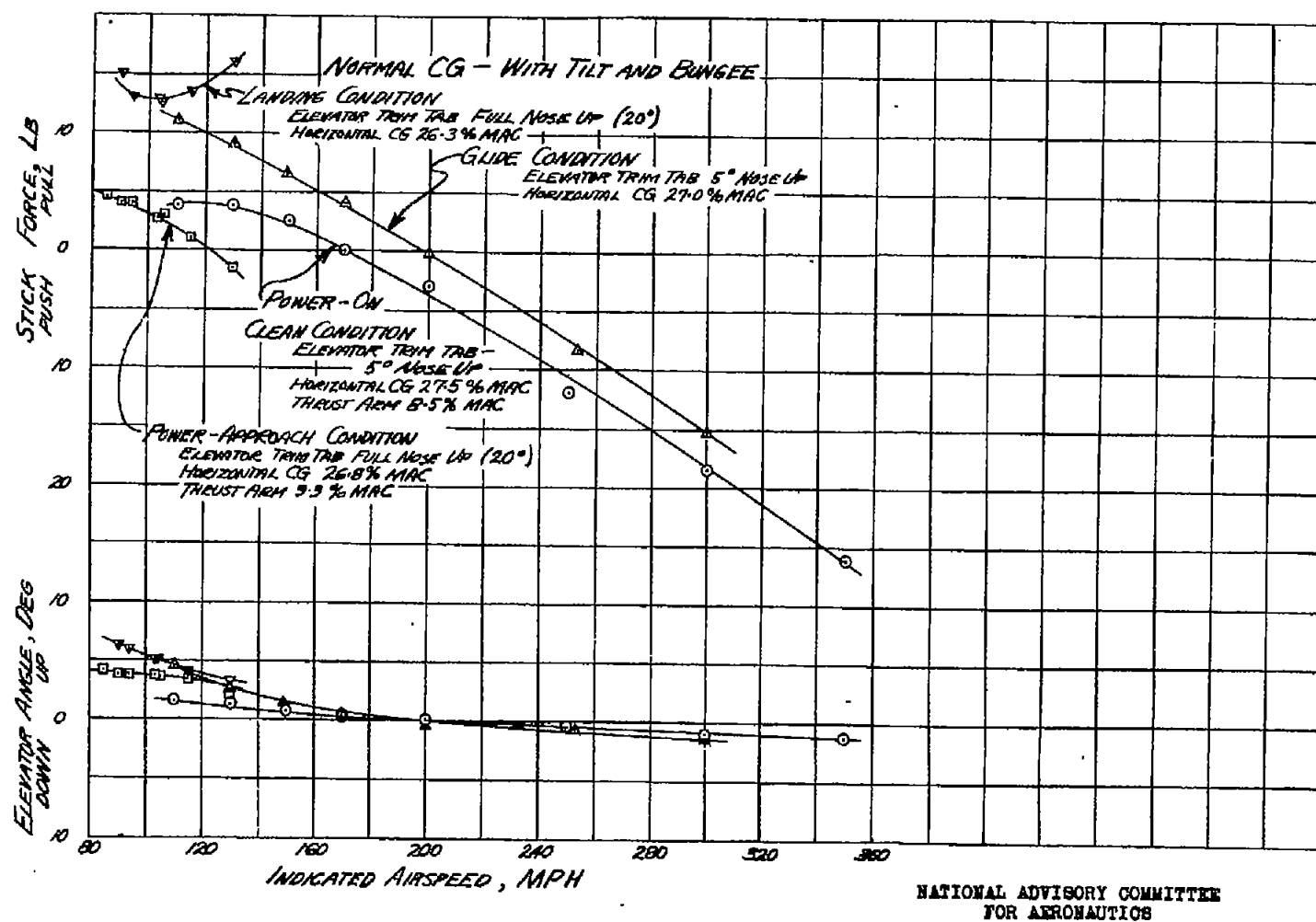
Fig. 9

Fig. 10

FIGURE 10. — STATIC LONGITUDINAL STABILITY AT NORMAL CG WITH BOTH ENGINE TILT AND STICK FORCE BUNGEE MODIFICATIONS.
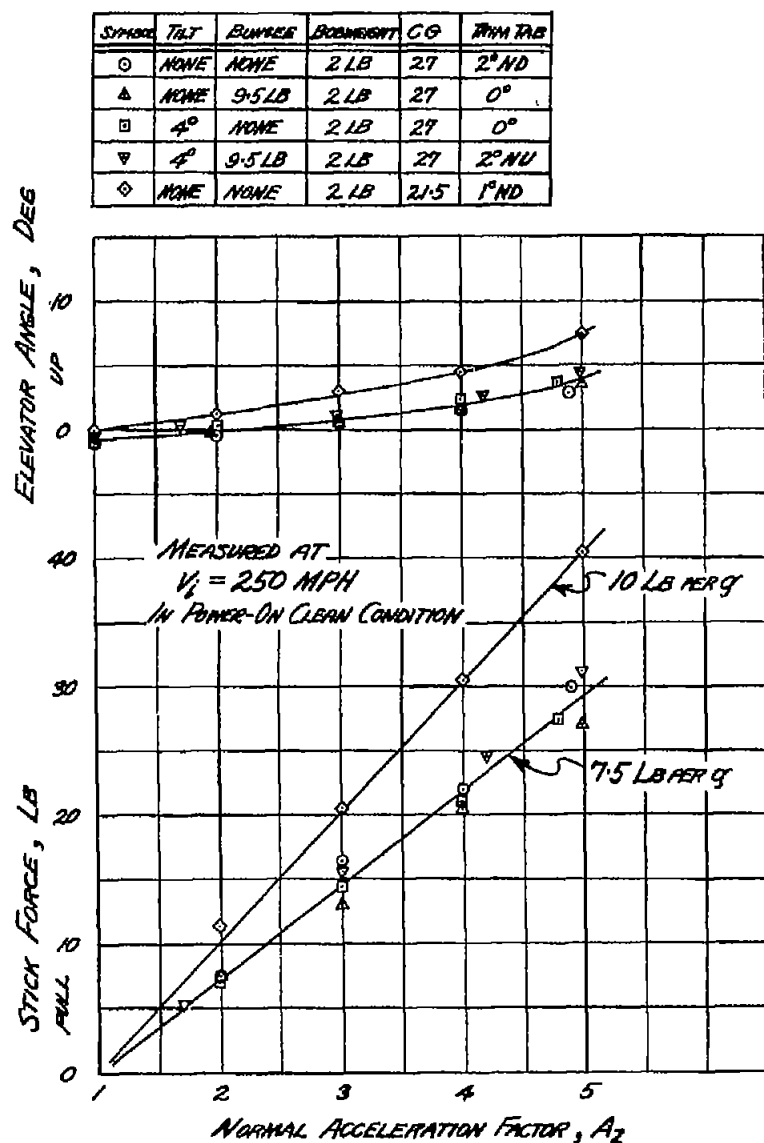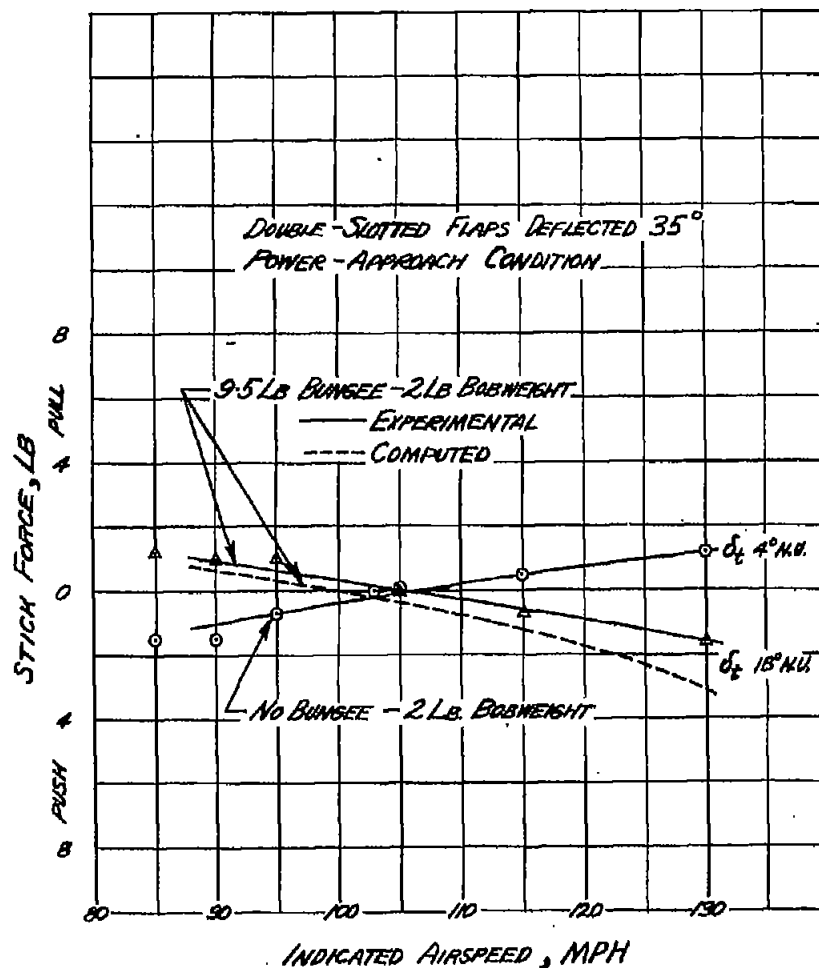
Symbol	Tilt	Bungee	Bobweight	C.G.	Trim Tab
⊙	None	None	2 LB	27	2° N.D.
△	None	9·5 LB	2 LB	27	0°
▣	4°	None	2 LB	27	0°
▽	4°	9·5 LB	2 LB	27	2° N.U.
◇	None	None	2 LB	21·5	1° N.D.

MEASURED AT
$V_i = 250$ MPH
IN POWER-ON CLEAN CONDITION

10 LB PER g

7·5 LB PER g

ELEVATOR ANGLE, DEG   UP

STICK FORCE, LB   PULL

NORMAL ACCELERATION FACTOR, A_z

FIGURE 11. — THE EFFECT OF THE TWO MODIFICATIONS ON THE
STICK-FORCE CHARACTERISTICS OF THE AIRPLANE
IN MANEUVERING FLIGHT.

DOUBLE-SLOTTED FLAPS DEFLECTED 35°
POWER-APPROACH CONDITION

9·5 LB BUNGEE — 2 LB BOBWEIGHT
——— EXPERIMENTAL
---- COMPUTED

δ_t 4° N.U.

δ_t 18° N.U.

NO BUNGEE — 2 LB. BOBWEIGHT

STICK FORCE, LB   PULL   PUSH

INDICATED AIRSPEED, MPH

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FIGURE 12. — THE EFFECT OF AN ELEVATOR STICK
FORCE BUNGEE ON THE STICK-FREE STATIC
LONGITUDINAL-STABILITY CHARACTERISTICS OF
THE AIRPLANE IN THE POWER-APPROACH
CONDITION.
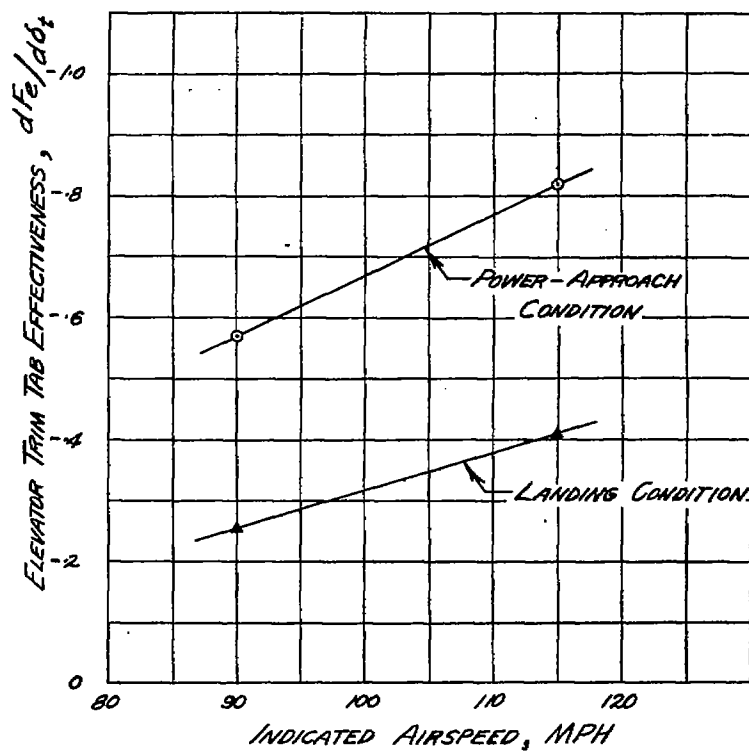
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FIGURE 13. ———— ELEVATOR TRIM-TAB EFFECTIVENESS
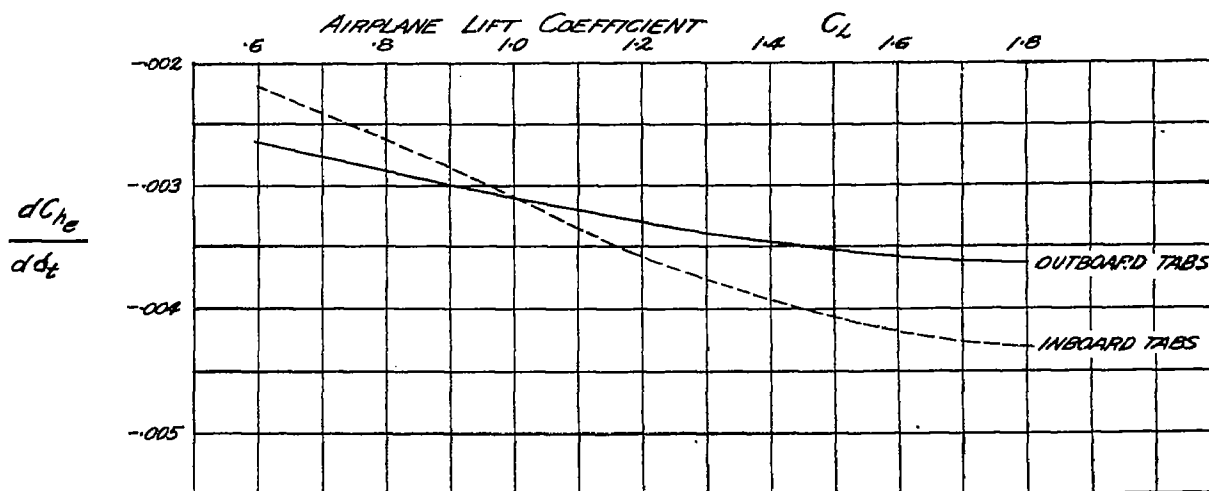OF THE TEST AIRPLANE.

FIGURE 14. ———— ELEVATOR TRIM-TAB EFFECTIVENESS FOR INBOARD AND OUTBOARD
TAB LOCATIONS, TEST AIRPLANE IN THE POWER-APPROACH CONDITION.
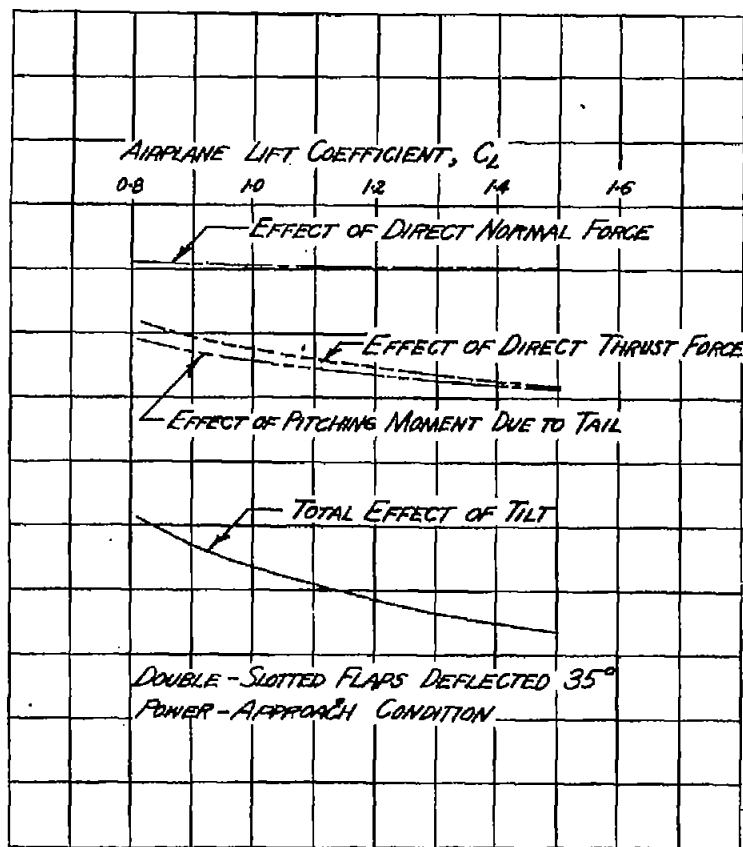
FIGURE 15. ——— THE EFFECT OF ENGINE TILT ON THE AIRPLANE PITCHING MOMENT.
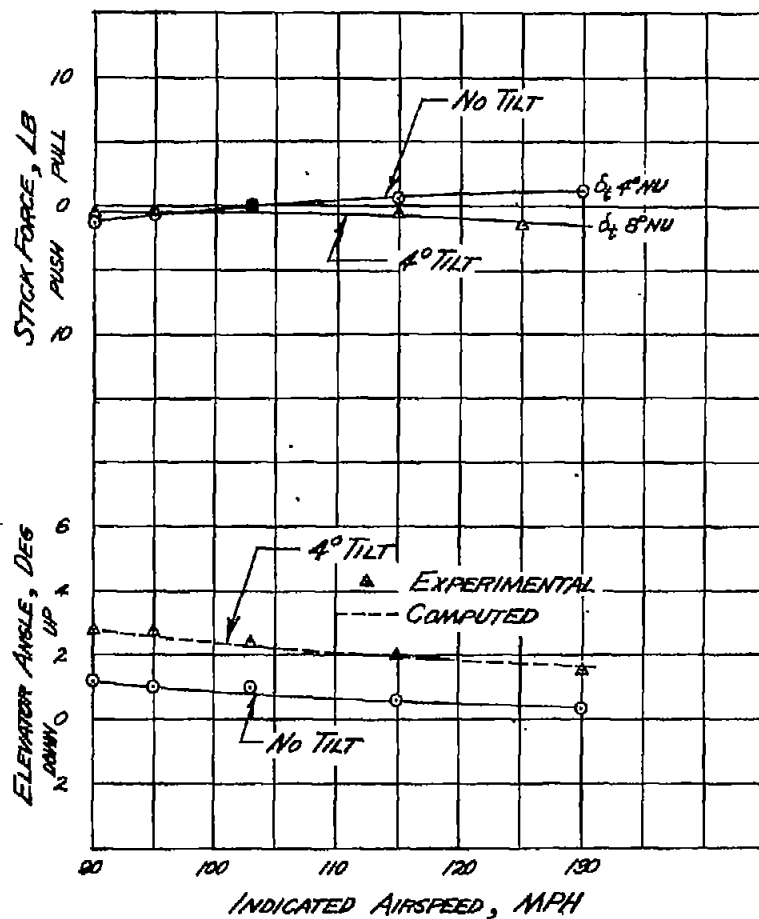
FIGURE 16. ——— THE EFFECT OF ENGINE TILT ON THE STATIC LONGITUDINAL-STABILITY CHARACTERISTICS IN THE POWER-APPROACH CONDITION.